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NOISE STABILITY OF THE TRANSMISSION OF SIGNALS WITH PULSE-CODE --ETC(U)
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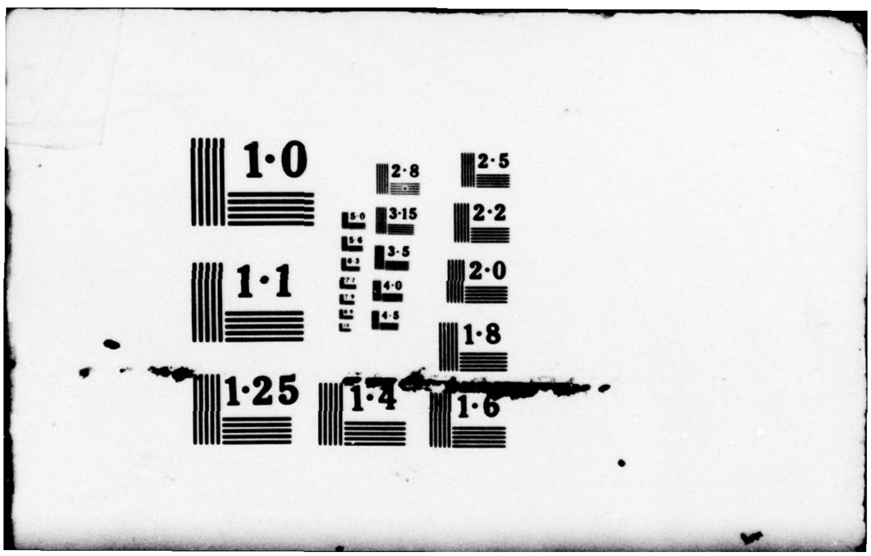
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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

NOISE STABILITY OF THE TRANSMISSION OF SIGNALS WITH PULSE-CODE MODULATION OVER OPTICAL LINES OF COMMUNICATION

By

N. M. Pavlov and L. A. Mayorova

FOREIGN TECHNOLOGY DIVISION

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EDITED TRANSLATION

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

NOISE STABILITY OF THE TRANSMISSION OF SIGNALS WITH PULSE-CODE MODULATION OVER OPTICAL LINES OF COMMUNICATION

N. M. Pavlov and L. A. Mayorova

In this article * an analysis is made of the reception of signals with pulse-code modulation over optical lines of communication with direct read-out when using on the output of the photo-detector a filter with characteristics which ensure a pulse spectrum which changes according to the law $\cos^2 x$. It is shown that with the particular method of reception the noise stability is close to potential in the case of reception using the method of photon count.

* Submitted 28 February 1973,

It has been demonstrated in a number of published works [1-3] that for the optimal detection of optical signals it is necessary to use short light pulses. However, in the case of transmission of signals with IKM [pulse-code modulation] the gating of the pulse and the count of the number of photons on a short time interval are necessary.

The direct counting of the number of photons with a high velocity presents certain difficulties, therefore it is desirable to use methods of reception, in which it is not required to make a direct count of the number of photons, but the noise stability of which will be close to potential.

In this paper a method of reception corresponding to the block diagram in Figure 1 is considered. As is shown below, this method of reception corresponds to the mode of photon count and ensures a potential noise stability with a pulse duration striving for zero and a signal spectrum on the input of the resolving device which is determined by the expression

$$S(\omega) = en \cdot e^{-j\omega t_0} \cos^2 \frac{\pi\omega}{2\omega_{гр}}, \tag{1}$$

where e - charge of electron,

n - number of photoelectrons in a pulse,

ω - present frequency,

$\omega_{гр}$ - upper boundary frequency of the spectrum,

t_0 - time delay of the signal on the output of the filter.

Since actually the pulse duration will have a finite magnitude, then it is necessary to determine the noise stability of the OLS [optical line of communication] in the presence of a finite pulse duration.

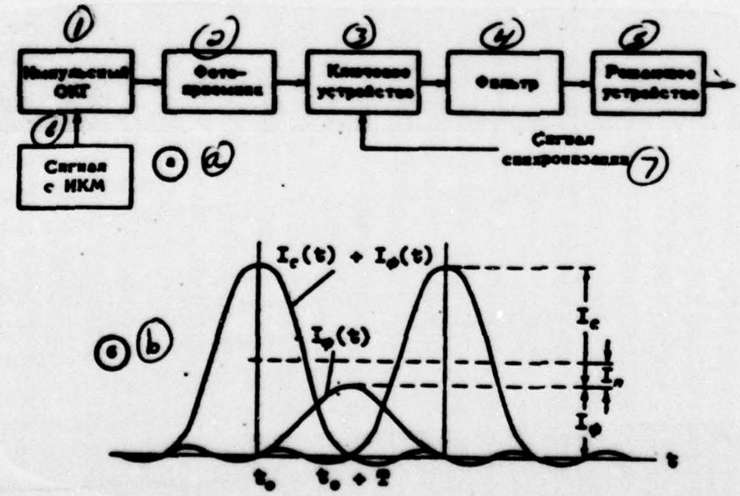

Figure 1.

Key: (1) Pulsed laser; (2) Photodetector; (3) Key device; (4) Filter; (5) Resolving device; (6) Signal with IKM; (7) Synchronization signal.

For simplification of the calculations it is assumed that:

- the source of light radiation operates in a pulsed mode;
- on the output of the source of light radiation the light pulses have a rectangular form;
- the photodetector is inertialess, and all the frequency limitations are determined by the filter on the output of the photodetector;
- on the output of the photodetector there is a key device (KU) which passes the signal only in the interval of the pulse duration.

Since the pulse of the signal on the output of the filter passes through zero at the moment $\pm(T_{zp} + t_0)$ (Figure 1), where $T_{zp} = \frac{2\pi}{\omega_{zp}}$, then the pulse repetition period T is accepted as equal to T_{zp}. Therefore the maximum possible pulse duration $\tau_{max} = T_{zp}$.

According to [4] the correlation function of a nonstationary photocurrent on the output of an inertialess photodetector is written in the form:

$$K(t_1,t_2) = e^2\lambda(t_1)\cdot\delta(t_2 - t_1) + e^2\lambda(t_1)\lambda(t_2), \qquad (2)$$

where $\lambda(t)$ - instantaneous flow density of photoelectrons;
e - charge of electron;
$\delta(t)$ - delta function.

Considering initially the passage of one pulse over the OLS, it is possible to write:

$$\lambda(t) = \lambda_0 K(t),$$

where λ_0 - instantaneous flow density of photoelectrons within the limits of pulse duration;

$$K(t) = \begin{cases} 1 & \text{- within the limits of pulse duration} \\ 0 & \text{- outside of the limits of pulse duration.} \end{cases}$$

The spectrum of a pulse of current on the input of the filter can be presented in the form:

$$S(\omega)_{\delta x} = I_0 T_m \frac{\sin\frac{\omega T_m}{2}}{\frac{\omega T_m}{2}}, \qquad (3)$$

where I_o - magnitude of current in a pulse.
It is evident that $I_o T_m = en$, where n - number of photoelectrons in a pulse.

It is shown in [5] that for ensuring the noise stability of reception of pulsed signals it is expedient to have a spectrum of pulse on the output of the receiving device which corresponds to expression (1).

From expressions (1) and (3) the transmission characteristics of the filter are determined:

$$K(\omega) = \frac{\omega T_m}{2} \frac{\cos^2\frac{\pi\omega}{2\omega_{cp}}}{\sin\frac{\omega T_m}{2}} e^{-j\omega t_0}. \qquad (4)$$

For the evaluation of noise stability of this particular case of reception depending on porosity we sill assume the possibility of error as constant for all values

$$\alpha = \frac{T_m}{T_{m\,max}}. \qquad (5)$$

It can be shown that in expressions (1), (3) and (4) the magnitude of the signal on the input of the resolving device (RU) depends on α and is proportional to the number of photoelectrons.

The probability of error in the case of reception "1" is determined by the expression

$$P_{om_1} = \int_{-\infty}^{-(U_1 - U_n)} W_1(x)dx,$$

where $W_1(x)$ - density of the probability of distribution of noise on the input of the resolving device at the moment t_0 in the case of transmission "1";

I_c - magnitude of useful signal on the input of the resolving device (RU) at the moment t_0;

$I_п$ - threshold value of RU (see Figure 1, b).

The probability of error in the case of reception "0" is determined from the expression:

$$P_{ош_0} = \int_{I_п}^{\infty} W_0(x)dx,$$

where $W_0(x)$ - density of probability of distribution of noise at the moment $T + t_0$ in the case of reception "0."

The distribution of the density of noise probability on the output of the filter was assumed normal.

Considering the pulse of current on the output of the key device as the total current, caused by the signal, and the current, caused by the background radiation, it is possible to write:

$$P_{ош_1} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\frac{I_c - I_п}{\sqrt{D_1(\alpha) + D_\phi(\alpha)}}} e^{-x^2/2} dx; \quad P_{ош_0} = \frac{1}{\sqrt{2\pi}} \int_{\frac{I_п}{\sqrt{D_c(\alpha) + D_\phi(\alpha)}}}^{\infty} e^{-x^2/2} dx,$$

where $D_1(\alpha)$ - dispersion of noise, dictated by the pulse signal at the moment t_0 in the case of unit reception;

$D_\phi(\alpha)$ - dispersion of noise, dictated by background radiation at the moment t_0;

$D_c(\alpha)$ - dispersion of noise, dictated by the useful signal at the moment $T + t_0$ in the case of null reception.

Assuming that $P_{ош_1} = P_{ош_0}$, we obtain

$$\frac{I_c(\alpha)}{I_c(0)} = \sqrt{\frac{D_c(\alpha)}{D_1(0)} + \frac{D_\phi(\alpha)}{D_1(0)}} + \sqrt{\frac{D_1(\alpha)}{D_1(0)} + \frac{D_\phi(\alpha)}{D_1(0)}}. \qquad (6)$$

Expression (6) determines the noise stability of reception in a function of α, since the ratio $\frac{I_c(\alpha)}{I_c(0)}$ represents the ratio of the

necessary signal powers on the input of the photodetector.

For the evaluation of noise stability it is necessary to calculate $D(\gamma,\alpha)$ at the moments of gating by the resolving device.

Dispersion on the output of the filter can be determined in accordance with [6] by using the formula:

$$D_{\text{ш}}(t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(t_1 - \tau_1)\cdot G(t_2 - \tau_2) K_{\text{ш}}(\tau_1, \tau_2)\, d\tau_1 \cdot d\tau_2, \tag{7}$$

where $G(t)$ - pulse characteristics of the filter.
Substituting the expression for $K_{\text{ш}}(\tau_1, \tau_2)$, into formula (7), we obtain the dependence of dispersion on time on the output of the filter:

$$D_{\text{ш}}(t) = e^2 \lambda_0 \int_{-\infty}^{t} G^2(t - \tau)\, d\tau. \tag{8}$$

When $t = \frac{T_{\text{и}}}{2}$

$$D_{\text{ш}}(t) = e^2 \lambda_0 \int_{-T_{\text{и}}/2}^{T_{\text{и}}/2} G^2(t - \tau)\, d\tau. \tag{8'}$$

The pulse characteristics of the filter are determined on the basis of formula (4):

$$G(t) = \frac{4}{\pi T_{ap}} \int_0^{\pi/2} 2\alpha x \frac{\cos^2 x}{\sin 2\alpha x} \cos \gamma x\, dx. \tag{9}$$

The integral in expression (9) is not tabular. Utilizing the expansion of the integrand expression into a power series, we obtain:

$$G(t) = \frac{1}{T_{ap}} \left\{ b_0 + b_2 \gamma^2 + b_4 \gamma^4 + \dots \right\}, \tag{10}$$

where

$$h_m = \frac{4(-1)^{m/2}}{\pi \cdot m!} \sum_{j=m/2}^{p/2} \frac{\left(\frac{\pi}{2}\right)^{2j+1} d_{2j-m}}{2j+1},$$

$$d_m = b_m - \sum_{j=1}^{m/2} c_{2j} d_{m-2j}, \quad b_m = \frac{2^{m-1}(-1)^{m/2}}{m!},$$

$$c_{2j} = \frac{(-1)^j (2\alpha)^{2j}}{(2j+1)!}. \tag{11}$$

p/2 - number of members in expression (10)
Substituting expression (9) into (8'), we obtain

$$D(t) = \frac{e^2 n}{T_{2p}^2} \left\{ \sum_{j=0}^{p/2} \frac{g_{2j}(2\alpha)^{2j}}{2j+1} + \sum_{j=1}^{p/2} \frac{\gamma^{2j}}{(2j)!} \left[\sum_{l=j}^{p/2} g_{2l}(2\alpha)^{2l-2j} \prod_{i=0}^{j-1} (2i-1) \right] \right\}, \tag{12}$$

where $g_m = \sum_{j=0}^{p/2} h_{2j} h_{m-2j}$.

It is evident from an analysis of expression (12) that when $t = t_0$ the variable which is enclosed in the braces characterizes a lessening of noise stability in comparison with the mode of photon count (when $\alpha=0$, corresponding to the mode of photon count, the variable enclosed in the braces is equal to 1 with $t = t_0$).

Calculations of $D(\gamma,\alpha)$ were made on a "MIR" computer. The results of the calculation of $D(\gamma,\alpha)$ are given in Figure 2.

It can be shown that in expression (6)

$$\frac{D_\phi(\alpha)}{D_1(0)} = \frac{D_1(\alpha)}{D_1(0)} k\alpha,$$

where $k = \frac{n_\phi}{n_c}$;

n_ϕ - average number of background photoelectrons in the interval T;

n_c - average number of signal photoelectrons on a pulse.

Figure 3 shows the dependence of the noise stability of the system, which is shown in Figure 1, on the magnitudes of α and k.

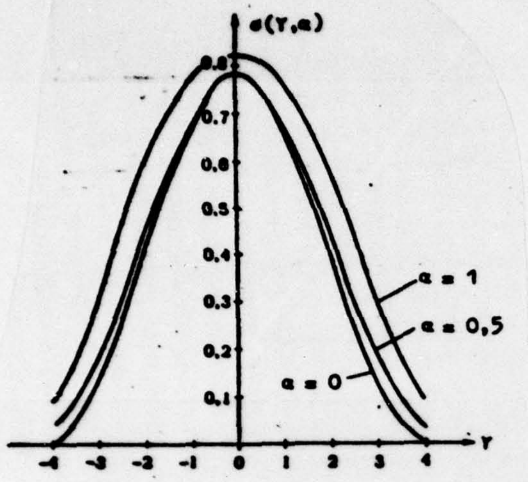

Figure 2.

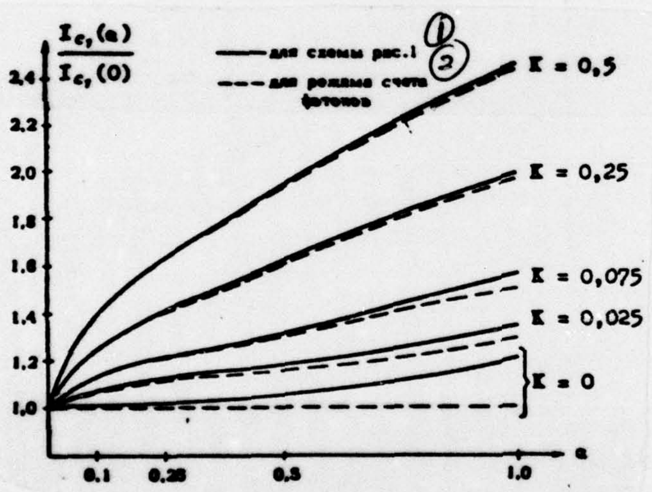

Figure 3.
Key: (1) for the layout in Figure 1; (2) for the mode of photon count.

The results obtained make it possible to draw the conclusion that the method of reception using the layout in Figure 1 possesses

a noise stability which is close to potential. The lowering of noise stability in comparison with potential comprises no more than 0.8 dB. The use of a gas laser with mode synchronization, a semiconductor laser, or a light diode in the pulsed mode of operation and the method of reception using the layout in Figure 1 make it possible to obtain a noise stability which is close to potential.

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